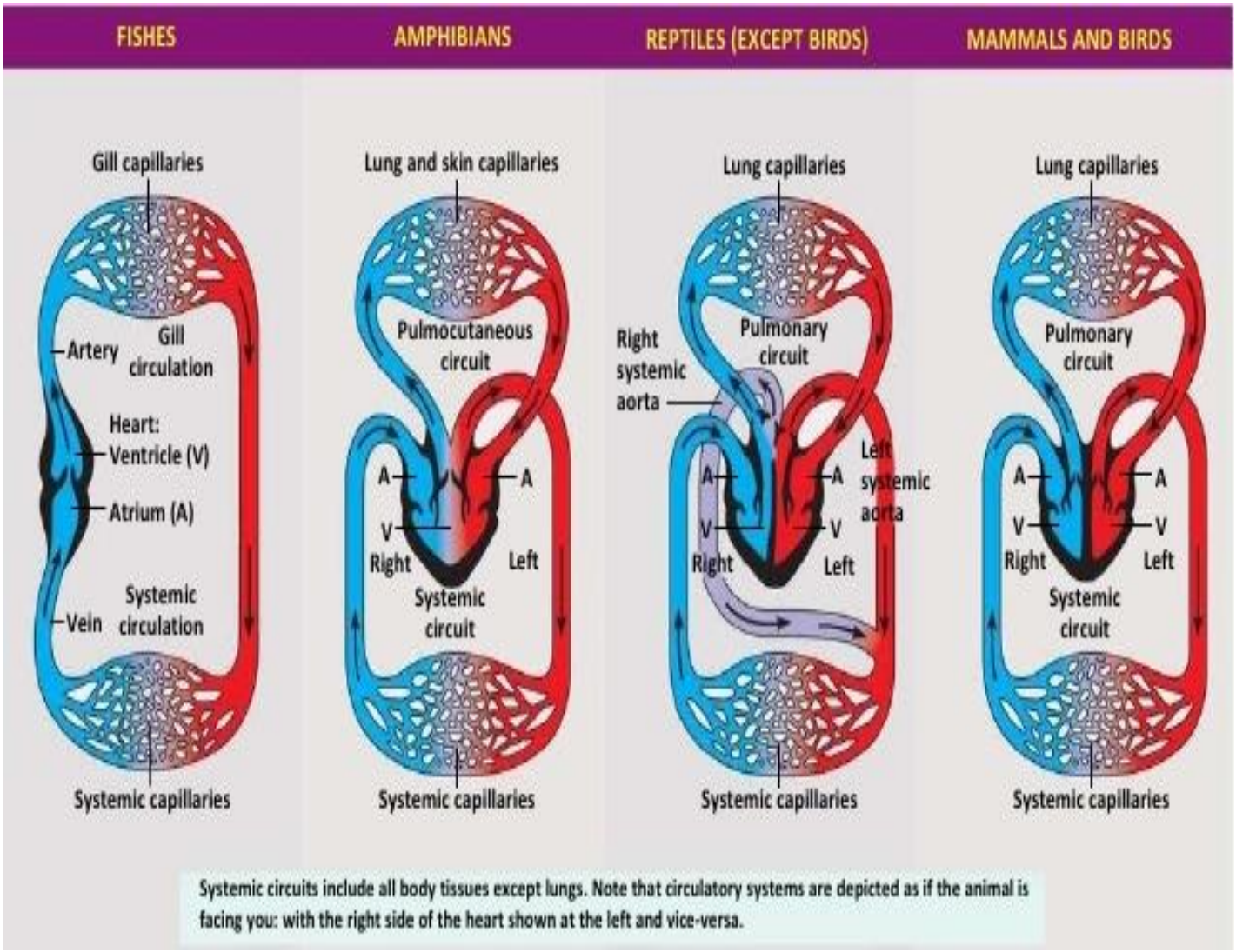
CIRCULATORY SYSTEM

General pattern of circulation in vertebrates



Systemic circuits include all body tissues except lungs. Note that circulatory systems are depicted as if the animal is facing you: with the right side of the heart shown at the left and vice-versa.

2. Expiration. Next, the mouth is closed by the action of adductor muscle. At the same time the constrictor and interbranchial muscles contract raising the floor of pharynx and reducing its volume. As a result, water is forced into gill pouches, over the gill lamellae, and out through the open external gill slits.

The spiracles are occasionally used as accessory pathways for entry of water for respiration, instead of the mouth, when it is occupied otherwise.

[III] Physiology of respiration

Each gill lamella has an extensive system of sinusoids which receive venous blood from an *afferent branchial artery* and pass it on to an *efferent* or *epibranchial artery*. During the passage of blood through this network, it becomes oxygenated. Fresh sea water entering the gill pouches contains O_2 dissolved in it. This O_2 passes by diffusion through the thin membranous and permeable capillary walls into blood. At the

Blood Vascular System

The circulatory system comprises 4 parts : (i) Heart and pericardium, (ii) arteries, (iii) veins and (iv) blood.

[I] Heart and pericardium

As in cyclostomes and other fishes, heart of *Scoliodon* receives venous blood only which it pumps into gills for aeration. Such a heart is called a *venous* or *branchial heart* (Figs. 16–18).

1. Position. The heart is situated mid-ventrally in head beneath the pharynx, supported below by the coracoid cartilages of the pectoral girdle. It lies within the *pericardial cavity* in a two-layered membranous *pericardium*.

2. Structure. Heart is a reddish-brown, muscular and dorso-ventrally bent, S-shaped tube differentiated into a series of 4 chambers : *sinus venosus*, *auricle*, *ventricle* and *conus arteriosus*, arranged in tandem formation. Of these only two, the auricle and ventricle, are considered to be true

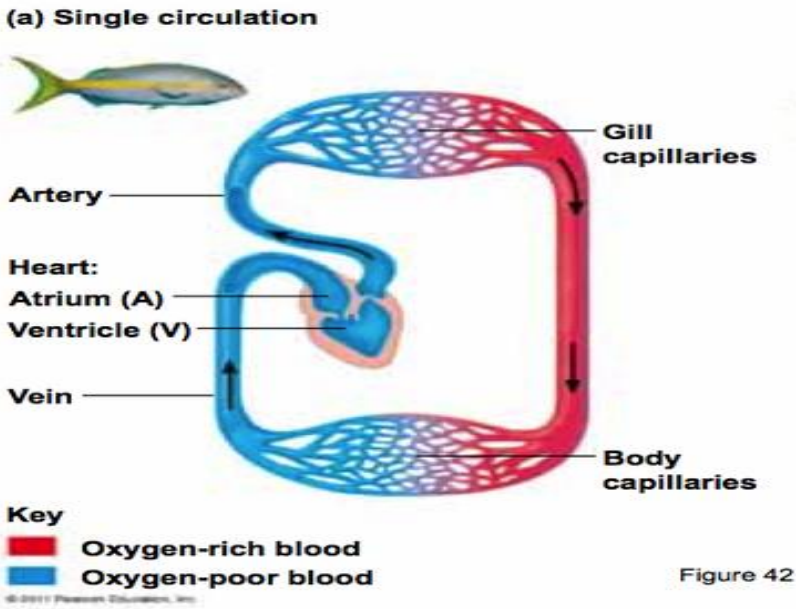


Figure 42

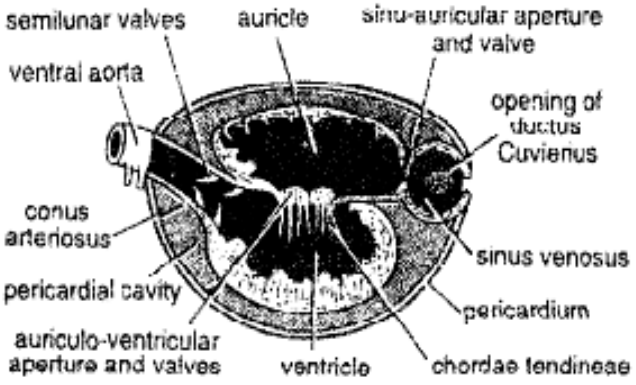


Fig. 17 *Scoliodon*. Heart and pericardium in sagittal section.

chambers so that heart is only *two-chambered* in fishes.

(a) Sinus venosus. It is the most posterior chamber. It is triangular, elastic, thin-walled and extending transversely across the posterior wall of pericardium to which it is fused. It receives venous blood through two large veins, called *ductus Cuvieri*, laterally one on either side, and through a pair of *hepatic sinuses* posteriorly. Apex of sius venosus opens anteriorly into auricle by a *sinu-atrial* or *sinu-auricular aperture* which is guarded by a pair of membranous valves which prevent backward flow of blood. It is highly contractile and the beating of the heart originates from this part of the heart.

(b) Auricle. The *atrium* or *auricle* lies in front of sinus venosus dorsally upon the ventricle. It is a large, triangular sac moderately muscular and with walls thicker than those of sinus venosus. Its two lateral sides projecting beyond the ventricle appear like ears. It opens into ventricle through an *auriculo-ventricular aperture* also guarded by two pocket like valves to prevent backward flow of blood.

(c) Ventricle. Ventricle is the most prominent and pear-shaped chamber of heart. Relatively small in size it has very thick muscular walls since it must propel blood to all parts of body. From the wall project internally numerous muscular strands thus giving it a spongy texture. *Chordae tendineae* are attached to opposite walls to prevent ventricle from expanding beyond its capacity.

(d) Conus arteriosus. Ventricle tapers anteriorly into a stout and muscular tube, the

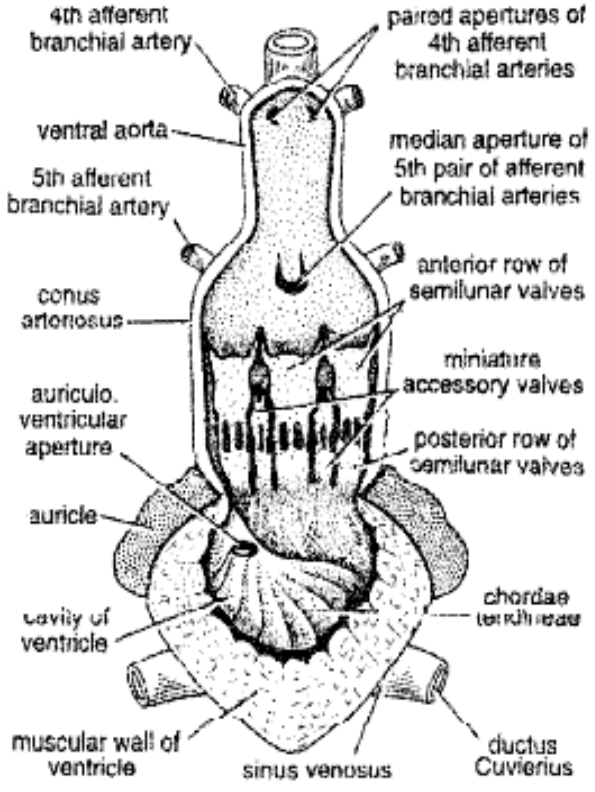
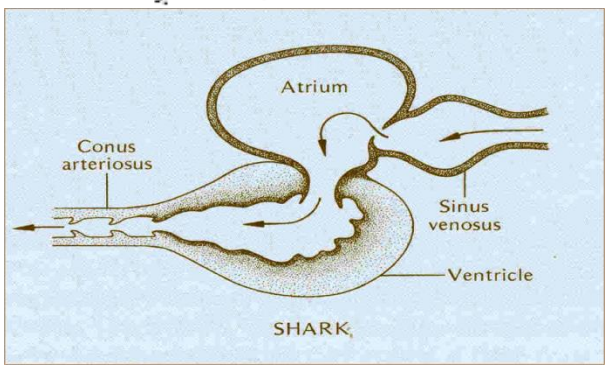


Fig. 18. *Scoliodon*. Heart dissected from ventral side to show internal structure.

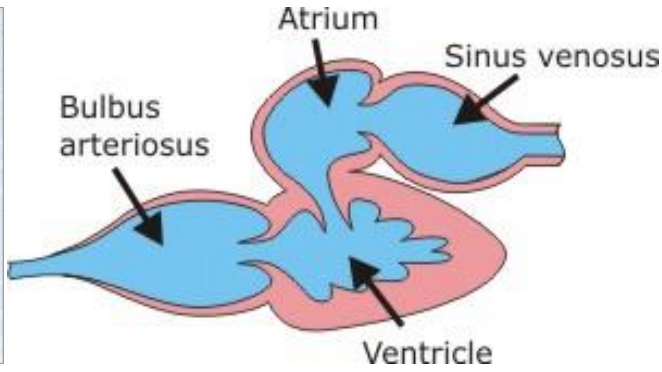
conus arteriosus. Cavity of conus contains two transverse rows of semilunar valves to block the regurgitation or backward flow of blood into ventricle. Each row has three valves, one dorsal and two ventro-lateral in position. A small accessory valve is also present on either side of each dorsal valve. Anterior valves are larger than the posterior ones. After perforating the anterior wall of pericardium the conus continues forward as the ventral aorta.

3. Working. Sinus venosus and auricle constitute the receiving chambers of the heart. Whereas, ventricle and conus arteriosus constitute the forwarding part of the heart. Heart of *Scoliodon* receives only deoxygenated or venous blood (*venous heart*). In a complete circuit of body, the blood passes through heart only once (*single circulation*). Heart works like a *muscular pump* for pumping its venous blood to the gills for aeration. To achieve this, different parts of the heart rhythmically contract at regular intervals and in a definite succession, first sinus venosus, then auricle, then ventricle and finally the conus

arteriosus. Each contraction, called *systole*, is followed by a relaxation, called *diastole*. Different valves of the heart serve to prevent the backward flow of blood into preceding chambers through the apertures that they guide. The walls of the heart are supplied oxygenated blood through special coronary arteries.



Heart of cartilaginous fish



Heart of bony fish

(B) Bony fishes

The blood vascular system and physiology of circulation are practically the same as in the dogfish *Scoliodon*. The 2-chambered *heart* lies in an anterior portion of coelom, the pericardium, beneath pharynx. *Sinus venosus* is large and spongy and bears a pair of lateral appendages characteristic of cyprinoid fishes including *Labeo*. It opens into thin walled *auricle*, thence into thick-walled *ventricle*, all having valves to prevent reverse flow of blood. Conus arteriosus is absent. Instead, an enlargement of *ventral aorta*, the elastic *bulbus arteriosus* is present. Short ventral aorta distributes blood to gill capillaries for oxygenation by 4 pairs of *afferent branchial arteries*. Oxygenated blood is collected by 4 pairs of *efferent branchial arteries* into *dorsal aorta* which sends branches to all parts of the head and body. Principal *veins* include paired anterior and posterior *cardinals*. Hepatic and renal portal systems are both present. The *erythrocytes* of bony fishes are considerably smaller than those of cartilaginous fishes and nucleated. Blood is pale colored fluid in which hemocytes and ameboid leucocytes are found suspended.

Amphibians

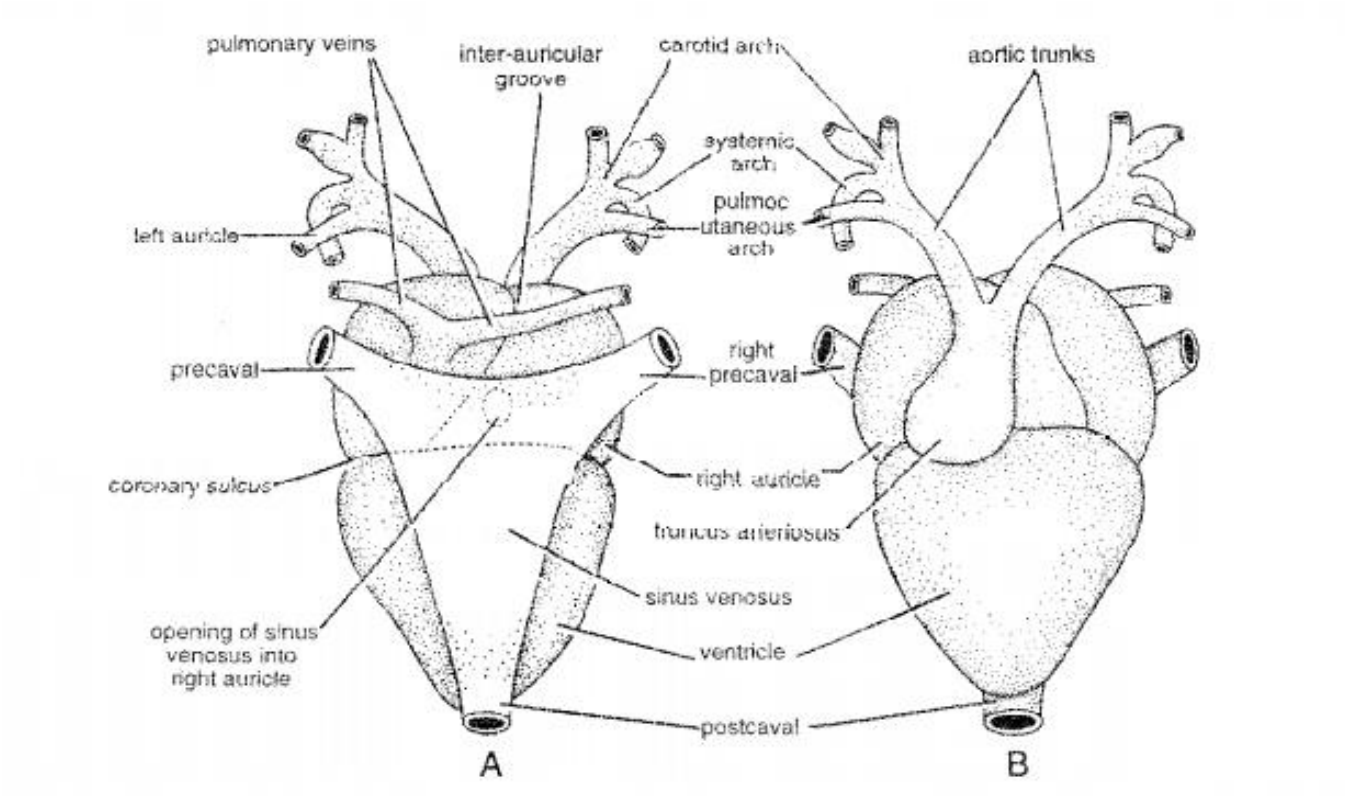
Blood-Vascular System

The blood vascular or circulatory system of frog is closed and includes : (i) heart, (ii) arterial system, (iii) venous system, (iv) blood, and (v) lymphatic system. Its chief function is to transport all necessary liquid and gaseous materials to the living tissues and also to bring away from them the liquid and gaseous wastes of metabolism to organs of elimination.

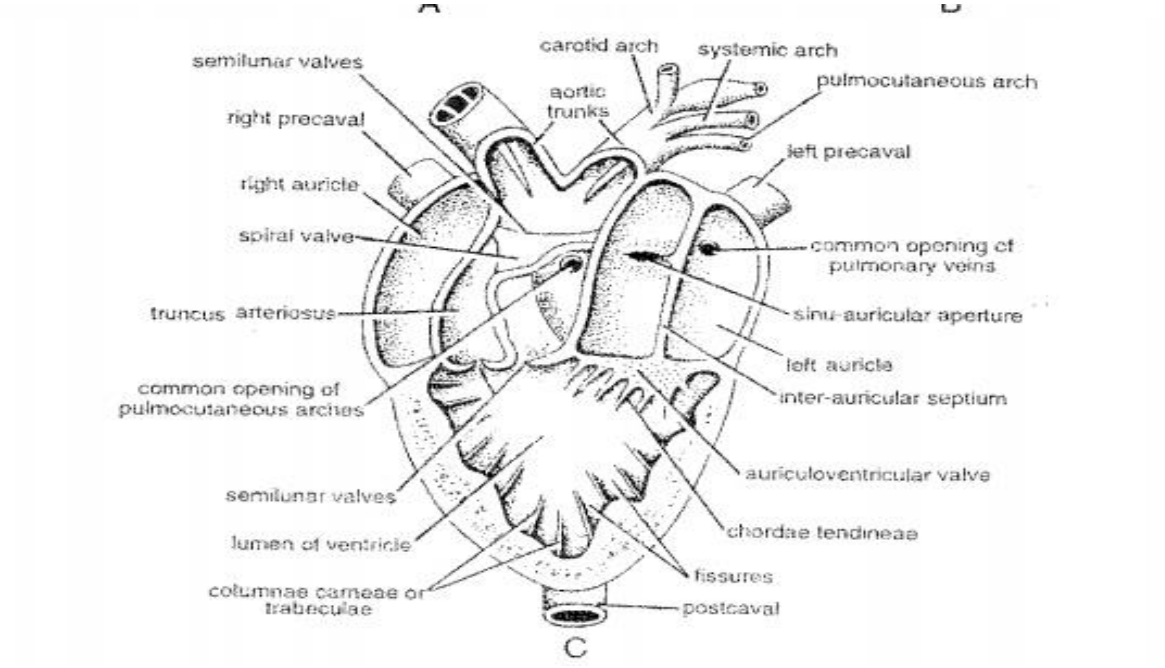
[I] Heart

The muscular heart is the central pumping station driving blood through the closed circulatory system (Fig. 20).

1. External features. The heart lies mid-ventrally inside the anterior trunk region protected by the pectoral girdle. It is reddish in colour and somewhat conical or triangular in shape



(A) Dorsal (B) Ventral view



with the broad base directed anteriorly and the narrow apex, posteriorly.

(a) Pericardium. The heart lies enclosed by a thin, transparent, two-layered sac, the *pericardium*. The outer wall of pericardium, *parietal pericardium* and inner one which closely invests the heart, called *visceral pericardium*. The narrow cavity between two pericardial layers contains a watery *pericardial fluid* which protects the heart from friction or mechanical shocks, keeps it moist and permits its movements.

(b) Chambers of heart. Frog's heart is a 3-chambered structure, made of two anterior dark-coloured *atria* or *auricles*, right and left, and a single posterior conical and pink-coloured *ventricle*. The two auricles are externally demarcated by a very faint longitudinal *inter-auricular groove*. However, the two auricles are clearly marked off from ventricle by a narrow transverse auriculo-ventricular groove or *coronary sulcus*.

The heart of frog has two *additional chambers* : *sinus venosus* and *truncus arteriosus*. *Sinus venosus* is a dark-coloured, thin-walled and triangular chamber attached dorsally to heart. It is formed by the union of three large caval veins, two anterior precavals and one posterior postcaval. *Truncus arteriosus* arising anteriorly from the right ventral side of ventricle, is a tubular chamber. It immediately bifurcates anteriorly into two branches or trunks, each further breaking into three arches : carotid, systemic and pulmocutaneous.

2. Internal structure. The internal structure of heart is seen in its section. It is hollow and muscular. The various chambers are separated by valves to keep the blood flowing in one direction.

(a) Auricles. The two auricles, right and left, are thin-walled and completely separated from each other by a thin vertical *inter-auricular septum*. Right auricle is larger than the left. Sinus venosus opens into dorsal wall of right auricle through a large transverse oval aperture, the *sinu-auricular aperture*. It lies medially close to the interauricular septum and guarded by a pair of flap-like valves. Similarly, the common pulmonary vein opens into left auricle, near septum by a small opening without valves. Both auricles open into single ventricle by a common large *auriculo-ventricular aperture* guarded by two pairs of flap-like *auriculo-ventricular valves*.

(b) Ventricle. The ventricle has thick muscular and spongy wall. Its inner surface has irregular strands or ridges, the *columnae carneae* or *trabeculae*, with depressions called *fissures*. These greatly reduce the cavity of ventricle. The flaps of auriculo-ventricular valves are connected to the wall of ventricle by thread-like *chordae tendineae*.

(c) Truncus arteriosus. The opening of ventricle into truncus arteriosus is guarded by 3 semilunar valves (4 according to Sharma, 1957) which prevent back flow of blood from truncus into ventricle. The spirally twisted cavity of truncus arteriosus is divided unequally by another set of 3 semilunar valves into a long basal thick-walled *conus arteriosus* or *pylangium* and a short distal thin-walled *bulbous aorta* or *synangium*. A large twisted longitudinal *spiral valve* further divides incompletely the cavity of conus or pylangium into a left dorsal *cavum pulmocutaneum* and a right ventral *cavum aorticum*. The spiral valve is attached dorsally while its ventral edge is free. The common opening of two pulmocutaneous arches lies in cavum pulmocutaneum, while separate openings of carotid and systemic arches lie in synangium. However, in *Rana tigrina*, Sharma (1957) describes a joint opening for systemic and carotid arches. All these openings are guarded by valves.

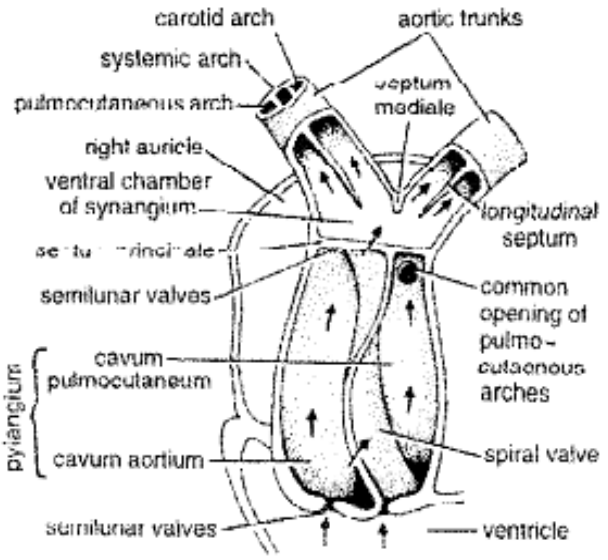


Fig. 21. Frog. Detailed internal structure of truncus arteriosus in ventral view.

The distal right and left branches or trunks appear externally to be single vessels but internally, each is made of 3 channels which eventually form three separate arches on either side (Fig. 21).

3. Working of heart. Heart is a muscular organ which constantly beats during life under nervous control to pump blood into the circulatory system. Contraction of heart is called *systole*, while its relaxation is termed *diastole*. Different chambers of heart contract in a regular sequence and the valves present, prevent the back flow of blood. When sinus venosus contracts, its nonoxygenated venous blood is forced into the right auricle through sinuauricular aperture. Mean while the oxygenated blood from lungs is poured into left auricle through common pulmonary vein. The two auricles now contract almost simultaneously forcing their blood into ventricle through the single auriculo-ventricular aperture.

(a) Old view. According to the conventional *older view* (Brucke, 1858), the ventricle contained only deoxygenated blood in its right side received from right auricle, and only oxygenated blood in its left side received from left auricle, with some mixed blood in the middle region. The two kinds of blood could not mix to any great extent because of their viscous nature and also because of the spongy nature of ventricle due to the

REPTILES

Blood Vascular System

The blood vascular or circulatory system of *Uromastix* is closed and consists of : (i) the heart, (ii) arterial system, (iii) venous system, and (iv) blood.

[I] Heart

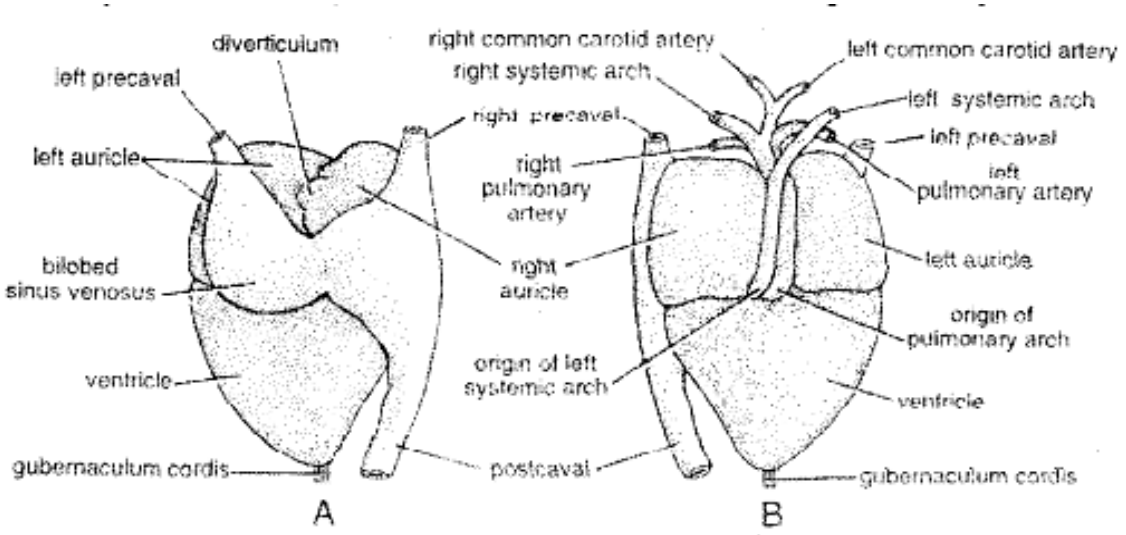
The heart of lizards (*Uromastix*) is typically reptilian and more advanced than that of Amphibia (Figs. 10–13).

1. External features. The heart lies midventrally and forward in the thoracic cavity, below the sternum. It is reddish in colour and roughly triangular in shape with its broad base, directed forwards and the pointed apex backwards.

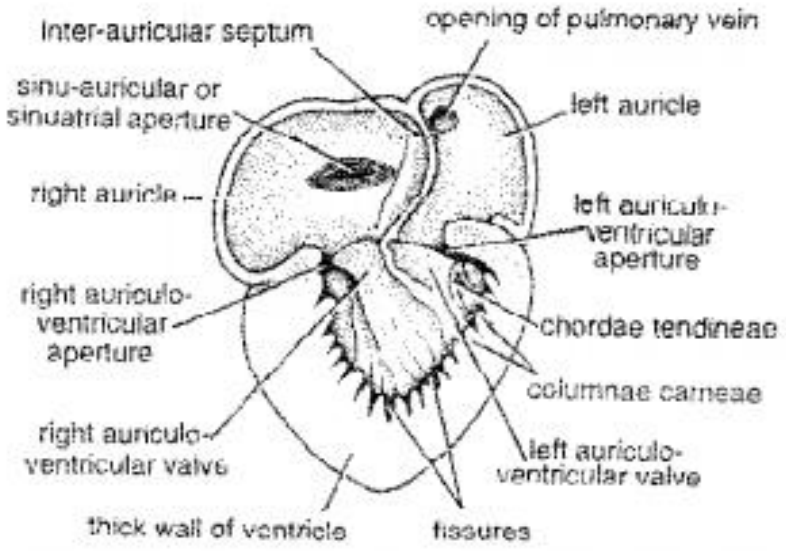
(a) Pericardium. The heart lies protected within a two-layered, thin, transparent sac, the *pericardium*. The two layers of pericardial sac enclose a narrow *pericardial cavity* containing a watery *pericardial fluid*, which allows free movements of the heart and also protects it from shocks and mechanical injuries. The apex of the heart remains attached to pericardial wall by a small cord, the *gubernaculum cordis*, which keeps the heart in position.

(b) Auricles. The heart itself is a three chambered organ, made of two anterior *auricles* or atria and a posterior *ventricle*. A fourth accessory chamber, the *sinus venosus*, is attached dorsally upon the auricles. The right and left auricles are faintly demarcated from one another by a longitudinal *interauricular groove*. The right auricle gives off a small sac-like *diverticulum* from its antero-medial border on the dorsal side. The diverticulum is a normal feature of the heart in certain lizards, but its function is unknown.

(c) Ventricle. The ventricle is a conical and highly muscular chamber. It is distinctly marked off from the auricles by a transverse *auriculo-ventricular* groove or *coronary sulcus*. The apex of ventricle is obtusely rounded and tied to posterior pericardial wall by a well-developed ligamentous cord, the *gubernaculum cordis*. It penetrates the pericardium and reaches the upper margins of the liver. The left lateral surface of ventricle is evenly convex, while its right lateral surface shows a slight concavity.



(A) Dorsal (B) Ventral view



Internal view

(d) Sinus venosus. A large thin-walled and bilobed chamber, called *sinus venosus*, is attached transversely over the dorsal surface of the two auricles. It is formed by the union of the two precaval veins and one postcaval vein. They collect deoxygenated blood from the body and open into sinus venosus by three separate apertures. A constriction divides sinus venosus externally into a larger right lobe and a smaller left lobe. The sinus venosus is attached intimately with the right auricle because it opens into it through a *sinu-auricular* or *sinu-atrial aperture*.

through a slit-like or oval sinu-atrial aperture.

2. Internal structure. The inner structure of the heart is visible in its section.

(a) Auricles. The two auricles or atria are thin-walled chambers completely separated by a thin, muscular and vertical partition, the *inter-auricular septum*. Its anterior end remains attached to the wall of the *auricles*, but the posterior end projects freely into the ventricle. The inner lining of auricular wall forms a network of low muscular ridges compared to *musculi pectinati* of higher vertebrates. The right auricle is larger than the left, a disparity commonly observed in lizards.

The dorsal wall of right auricle, near its medial border, bears the large oval or transverse slit-like *sinu-auricular aperture* of sinus venosus having thick and muscular lips. This aperture is often described in the books to be guarded by two flap-like valves. But, according to Bhatia (1929), the sinu-atrial valves are absent in *Uromastix hardwickii*. Instead, the thick and muscular lips serve to keep the aperture ordinarily closed, except when the blood is to be forced through it into the right auricle.

The common pulmonary vein, bringing oxygenated blood from the lungs, opens into the anterio-dorsal wall of the left auricle near the interauricular septum, by a small circular aperture. This aperture is usually devoid of valves in reptilian hearts. However, in *Uromastix hardwickii*, Bhatia (1929) describes a lip-like outgrowth from dorsal auricular wall which acts as a valve.

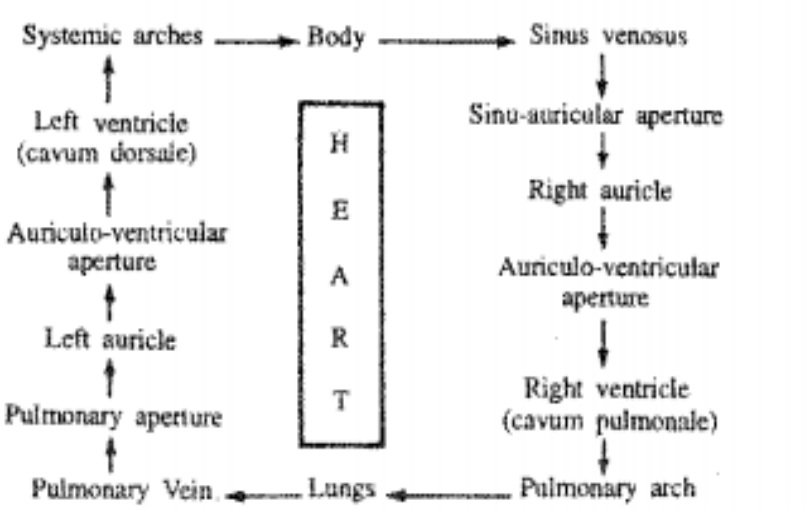
The two auricles communicate behind with the ventricle. Their respective right and left *auriculo-ventricular apertures* become separated due to a backward prolongation of the interauricular septum into the ventricle.

(b) Ventricle. The ventricle is single chambered. It has thick and muscular walls. The inner surface of ventricular wall is raised into prominent ridges, called *columnae carneae*, which greatly reduce the lumen of ventricle. Each auriculo-venticular aperture is guarded by a single semilunar flap, called the *auriculo-ventricular valve*. The two valves are the continuation of the inter-auricular septum into the ventricle. They allow the flow of blood only in one direction, i.e. from the auricles to the ventricle. The free edges of the valves are connected to the inner wall of the ventricle by firm cords, the *chordae tendineae*.

Right side of the ventricle receives deoxygenated blood from the right auricle and the left side receives oxygenated blood from the left auricle. The chordae tendineae form a sort of incomplete septum and keep the blood in the two sides of the ventricle partially separated.

Three *aortic arches*, one pulmonary and two systemic, arise directly and independently from the lumen of the ventricle, but not in the same plane. The *conus arteriosus* is absent. The pulmonary arch arises ventrally from cavum pulmonale, while the two systemic arches from cavum dorsale. Every arch has a pair of *semilunar valves* at its base which allow the flow of blood from the ventricle to the arch only.

3. Course of circulation. Deoxygenated blood from body is returne t sinus ven sus through caval veins. When sinus venosus contracts the blood is driven into the right auricle through sinu-atrial aperture. Meanwhile, the left auricle receives oxygenated blood from lungs through pulmonary vein. When the two auricles contract, the deoxygenated blood from right auricle passes into rig..t side of ventricle (cavum pulmonale), while oxygenated blood from left auricle occupies the left side (cavum dorsale). Inspite of the spongy nature of the ventricular cavity, some mixing of pure and venous blood may occur. When the ventricle contracts, venous blood from right side is driven through pulmonary arch to the lungs. Simultaneously, oxygenated and partly mixed blood from left side goes into systemic arches and distributed to the body. Head receives the purest blood. The valves prevent backward flow of blood during contraction.



Birds

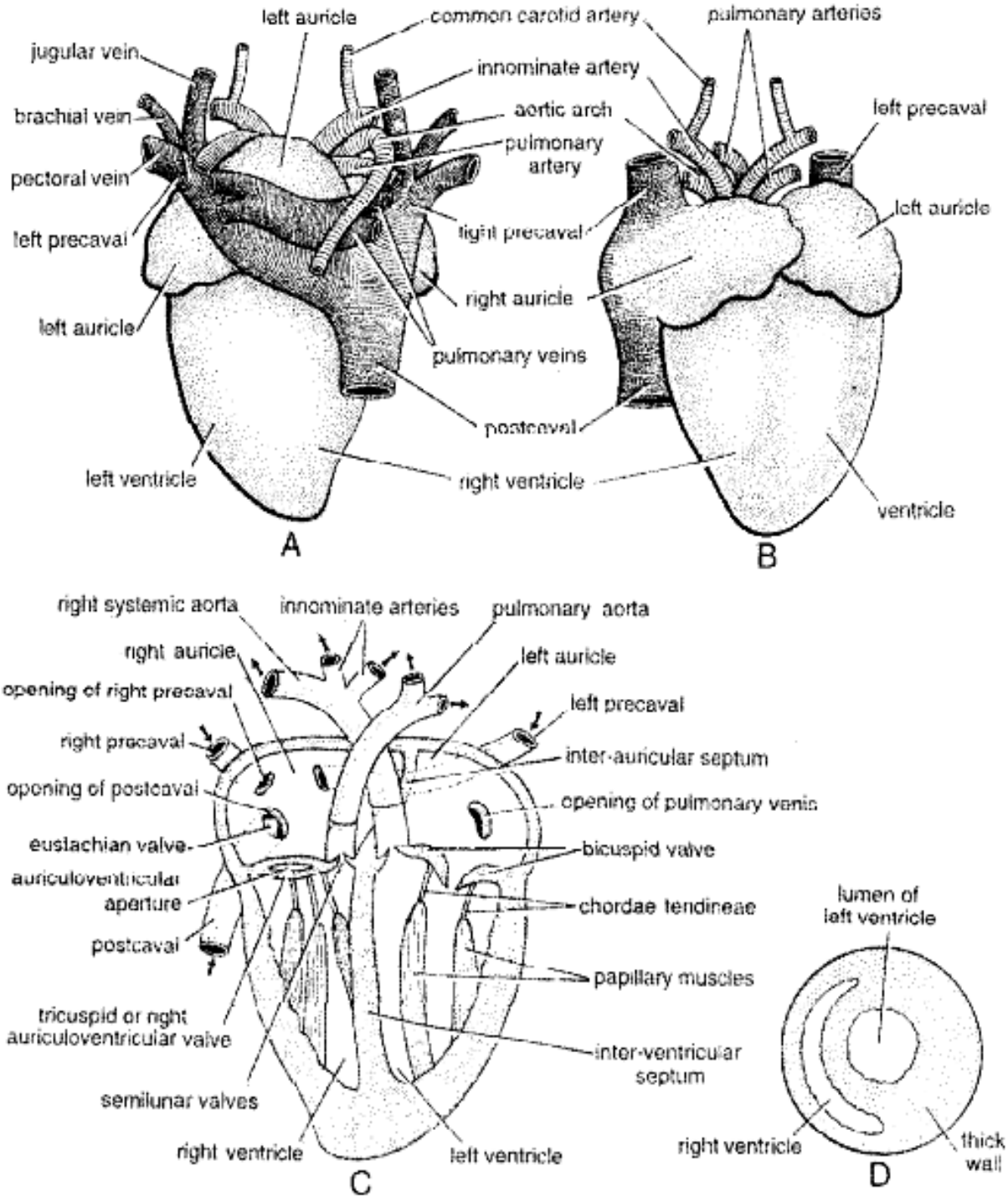
Circulatory System

The circulatory system is quite comparable, in structure, to that of other higher vertebrates. It consists of (i) heart, (ii) arteries, (iii) veins, (iv) lymphatic vessels and (v) blood.

[I] Heart

The birds show some advance over the ancestral reptiles in having a completely 4-chambered heart, with 2 *atria* or *auricles* and 2 *ventricles*, as in mammals. A *sinus venosus* or a *conus arteriosus* is absent. The sinus venosus is said to be incorporated into the right auricle (Fig. 21).

External features. The heart in birds is comparatively larger than in other vertebrates. It lies in the thoracic cavity, mid-ventrally, ventral to oesophagus, partly surrounded by the lobes of the liver. The heart is reddish in colour. It is conical in shape with the apex directed backwards and the broad base, forwards. It is enclosed in a thin, transparent and membranous sac, the *pericardium*, which is made of an outer parietal layer and an inner visceral layer. The two layers enclose a narrow *pericardial cavity*, filled with a watery *serous* or *pericardial fluid*, which protects the heart from shocks and injuries and permits movements during beating. An external hollow transverse groove, the *coronary sulcus* or the *auriculo-ventricular goove*, separates the two anterior, darker, smaller and thin-walled auricles from the posterior, lighter, bigger and thick-walled


left auricle
common carotid artery
pulmonary arteries
jugular vein
innominate artery
brachial vein
aortic arch
left precaval
pulmonary artery
pectoral vein
left auricle
left precaval
right precaval
right auricle
left auricle
pulmonary veins
postcaval
left ventricle
right ventricle
ventricle
A
B
right systemic aorta
innominate arteries
pulmonary aorta
right auricle
left auricle
opening of right precaval
left precaval
right precaval
inter-auricular septum
opening of postcaval
opening of pulmonary veins
eustachian valve
bicuspid valve
auriculoventricular aperture
chordae tendineae
postcaval
papillary muscles
tricuspid or right auriculoventricular valve
inter-ventricular septum
semilunar valves
right ventricle
left ventricle
C
lumen of left ventricle
right ventricle
thick wall
D

ventricles. Similarly, a faint *inter-auricular groove* demarcates the two auricles.

Internal structure. Internally, the two thin walled auricles are separated by a complete, thin membranous partition, the *inter-auricular septum*. It bears in its middle a small oval area, the *fossa ovalis*, representing the position of the foramen ovale in the embryo. The two ventricles are also completely separated from each other by a thick, muscular *inter-ventricular septum*. The *right auricle* is larger and receives the three large caval veins, the right and left precavals and the postcaval in its dorsal wall. The opening of the postcaval is guarded by a muscular *eustachian valve*. The right auricle opens into the *right ventricle* by a crescenitc aperture, the *right auriculo-ventricular aperture*. It is furnished with a pair of strong muscular flaps, without chordae tendineae, forming the *right auriculo-ventricular valve*. In function, it represents the *tricuspid valve* of the mammals. The right ventricle, having thinner walls, partly encircles the left ventricle, having thicker walls. In a transverse section the right ventricle appears crecentic, while the left ventricle appears circular. The right ventricle gives off a single trunk, the *pulmonary aorta*, which soon divides into two pulmonary arteries, each going to a lung. The opening of the pulmonary trunk is guarded by three *semilunar valves*.

The *left auricle* is smaller and receives four pulmonary veins from the lungs. It opens into the left ventricle by a circular *left auriculo-ventricular aperture*. It is guarded by two membranous flaps forming the *left auriculo-ventricular valve*, which corresponds to the *bicuspid* or *mitral valve* of mammals. The flaps are connected to thick *papillary muscles*, arising from the wall of the left ventricle by two *chordae tendineae*. The left ventricle gives rise to the single *right systemic* or *aortic, arch*, which is continued into the *dorsal aorta*. The left arch, which is present in the frog and lizard, is absent in birds. The opening into the aortic arch is guarded by three semilunar valves. Bars of muscles, called *trabeculae* or *columnae carneae*, traverse the cavities of the ventricles.

Working. The heart is a force-pump, which drives the blood to all parts of the body. As in mammals, the avian heart is completely four-chambered, so that there is complete separation of arterial and venous bloods. The right half receives and discharges only venous, the left only arterial blood. Thus, birds, like mammals, possess a complete *double circulation* of the blood, as follows :

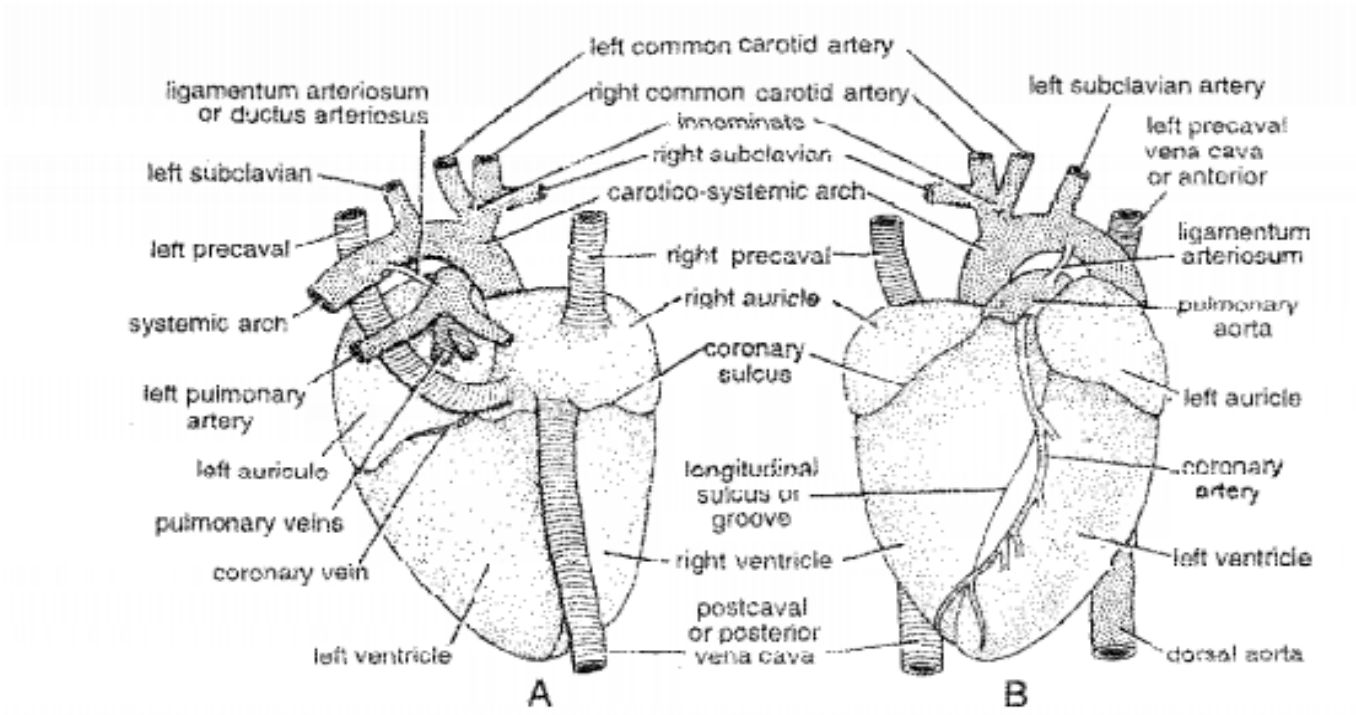
(a) Pulmonary circulation. The right ventricle pumps venous blood into the pulmonary aorta which divides into the right and left pulmonary arteries leading to the right and left lungs, respectively. From the lungs, oxygenated blood is returned to the left auricle by the 4 pulmonary veins.

(b) Systemic circulation. From left auricle the blood passes through the left auriculoventricular valve into the left ventricle. Thence, it is driven through the aorta into smaller arteries, which break up into capillaries and the blood nourishes all the tissues of the body. The capillaries unite to form veins, which finally form the three great venae cavae, which return the impure blood to the right auricle. From the right auricle it passes through the right auriculo-ventricular valve into the right ventricle, where the pulmonary circulation begins.

Mammals

Circulatory System

The body needs a transport or circulatory system for distributing digested food, water, oxygen, numerous secretions and waste products throughout the body. The chordates have a completely *closed* circulatory system. It includes (i) the *blood vascular system*, and (ii) the *lymphatic system*. The *blood* vascular system consists of closed tubes or



blood *vessels* (arteries, veins and capillaries), inside which a transporting fluid, the *blood*, is kept in circulation by a definite pumping organ, the *heart*. Thus, the blood vascular system of rabbit is composed of : (i) the heart, (ii) *arterial system*, (iii) *venous system* and (iv) *blood*.

[I] Heart

The heart of rabbit lies mid-ventrally between the two lungs inside the median space of the thoracic cavity, called *mediastinum*.

1. External features. The heart is a small, pear-shaped, muscular and hollow, four-chambered organ of reddish colour. It is placed somewhat obliquely. Its broad base is directed anteriorly towards right and the pointed apex posteriorly towards left.

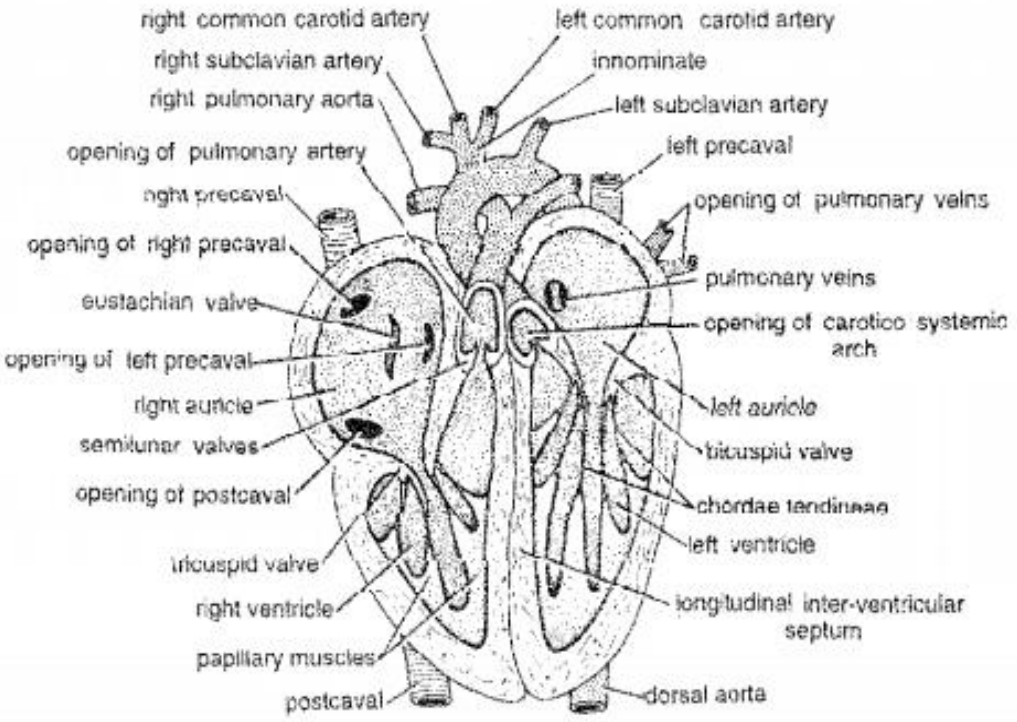
(a) Pericardium. The heart is completely enclosed by a transparent thin-walled and two-layered sac, the *pericardium* which is connected to the ventral thoracic wall and the posterior diaphragm to keep the heart in position. The two layers of pericardial sac, inner visceral and outer parietal, enclose a narrow space, the *pericardial cavity*, filled with a watery *pericardial fluid*, which allows free movements of the heart and also protects it from external shocks and mechanical injuries.

(b) External division. The heart is exposed on the removal of pericardium. A distinct transverse groove divides the heart into an anterior smaller and dark red *auricular part* and a posterior larger and paler *ventricular part*. This is known as the *auriculoventricular groove* or *coronary sulcus*.

(c) Auricles. The auricular part is divided into *right* and *left auricles* of which the left one is smaller than the right. The mammalian heart has *no sinus venosus* which is incorporated into the right auricle. Each auricle is produced behind into a swollen flap, the *auricular appendix*, which slightly covers the ventricle of its side.

(d) Ventricles. The ventricular part is also divided into *right* and *left ventricles* by a shallow *longitudinal interventricular groove*. It runs behind from the base of the heart somewhat obliquely towards right, without reaching the apex. Consequently, the right ventricle remains smaller whereas the left ventricle becomes larger and forms the rounded apex of the heart.

The mammalian heart has no *conus (truncus) arteriosus*, which is merged with the ventricles. The primitive *ventral aorta* has also been split in



such a way that the pulmonary artery leads from the right ventricle while the remainder part or *carotico-systemic* aorta connects with the left ventricle.

2. Internal structure. The main internal features of the heart can be seen in its longitudinal dissection, or removal of its ventral side wall. Internally, the heart is completely four-chambered divided into two anterior auricles and two posterior ventricles.

(a) Auricles. The two *auricles* or *atria* are thin-walled chambers, completely separated from each other by a thin, muscular and vertical partition, the *inter-auricular septum*. In the embryo, this septum bears an opening, called *foramen ovale*, through which both the auricles communicate with each other. But in the adult, this aperture is closed and represented by a small oval depression, the *fossa ovalis*. The inner lining of auricular wall forms a network of low muscular ridges, the *musculi pectinati*. The left auricle has thicker walls and is rather smaller than the right auricle.

The right auricle receives venous blood from different parts of the body through two precaval and one postcaval veins, having separate openings. The opening of postcaval is guarded by a rudimentary membranous fold, the *eustachian valve*. Near it lies the remnant of embryonic sinus venosus, called *sinuauricular node*.

The left auricle receives a single common *pulmonary opening* of the pulmonary veins returning oxygenated blood from the lungs. It has no valve.

Each auricle opens behind into the ventricle of its side through an *auriculo-ventricular aperture*. Each aperture is guarded by a valve made of a sheet of tough connective tissue. The *right auriculo-ventricular valve* consists of three triangular flaps or cusps and is known as the *tricuspid valve*. The left *auriculo-ventricular valve* consists of two flaps and is termed *bicuspid* or *mitral valve* because of its supposed resemblance to the miter (hat) worn by the bishops. Flaps of these valves are connected to *columnae cornea*, situated on the internal walls of ventricle with the help of *chordae tendinae*. These valves allow the flow of blood from auricle to ventricle only.

(b) Ventricles. Unlike auricles, the two ventricles are very muscular and thick-walled

chambers. They are also separated completely by a thick, oblique and vertical *inter-ventricular septum*. The left ventricle is larger with thicker walls and almost circular in a transverse section. It also forms the posterior apex of the heart. The right ventricle is smaller and crescentic in a transverse section. From the inner surface of the ventricular wall project low, irregular, muscular ridges, called the *columnae carneae*. Besides, there are few large conical or nipple-shaped elevations called *papillary muscles*. The flaps of the two auriculo-ventricular valves hang freely into the ventricular cavities. The free edges of the flaps are attached to papillary muscles by long, tough, white connective tissue strands, called *chordae tendineae*. When the ventricles contract, these chords prevent the flaps of these valves from being inverted into the auricular cavities.

Two large arteries arise anteriorly from the ventricles, the *pulmonary arch* or *aorta* from the right ventricle and the *systemic arch* or *aorta* from the left ventricle. The point where two arches cross each other, communicate with one another through *ligamentum arteriosum*. Each arch or aorta has at its base three pocket-shaped or cup-like *semilunar valves*, to prevent the backflow of blood from the arch into the ventricle.

(c) Double circulation. The completely four-chambered mammalian heart actually comprises two separate pumps working in union. The right side of the heart serves as one pump. It contains only venous blood, received from the body and sent to the lungs through *pulmonary circulation*. The left side of the heart serves as the second pump. It contains only oxygenated blood received from the lungs and sent to the body through *systemic circulation*. Thus, there is no mixing of venous and oxygenated bloods in the heart, and the blood passes through the heart twice, once along the pulmonary circuit and second time in the systemic circuit. This is known as the *double circulation* of blood. This is characteristic of mammals and birds.

(d) Course of blood circulation. As already mentioned, the venous blood from the general body circulation is returned to the right auricle through the caval veins. At the same time the oxygenated blood from the lungs enters the left auricle through pulmonary veins. Simultaneously, the two auricles contract *(auricular systole)*, forcing their bloods into the corresponding ventricles through their auriculo-ventricular apertures. Venous blood from right auricle passes through tricuspid valve into right ventricle, while oxygenated blood from left auricle goes through bicuspid valve into left ventricle.

As the emptied auricles relax *(auricular diastole)*, the two ventricles contract with sufficient force *(ventricular systole)*. The great pressure closes the valves between ventricles and auricles preventing backward flow of blood into the auricles. At the same time the semilunar valves at the bases of aortic arches open. Thus the venous blood of right ventricle is forced into the pulmonary aorta and carried to the lungs for aeration. The oxygenated blood of left ventricle is pumped into the systemic aorta and distributed throughout the body. When the ventricles relax *(ventricular diastole)* the pressure of blood inside the aortae causes closure of the semilunar valves.